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Procedia Social and Behavioral Sciences 2 (2010) 7718–7719

Procedia
Social and Behavioral Sciences

Sixth International Conference on Sensitivity Analysis of Model Output

Senstitivity analysis for spatial simulation of urban growth

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Abstract

In any model, sensitivity analysis (SA) is a fundamental process to improve the robustness and credibility of the results. Generally, SA is carried out by testing whether small variations in the input parameters could affect the results of the model. More complex techniques of SA have been developed within the field of numerical modelling; however, they have limited application for spatial models, as they do not consider variations in the spatial distributions of the variables included in the model. In this research, an explicitly spatial methodology for SA is proposed. It uses the tools available in a raster GIS environment (Idrisi) and has been tested in a simulation of future urban growth for the region of Madrid (Spain).

Keywords: Sensitivity Analysis; Geographical Information System; Multi-Criteria Evaluation; Sensitivity Analysis

1. Main text

Land planning processes seem to evolve towards more participatory approaches, integrating the views of different stakeholders for the generation of models reflecting sustainabiltiy principles. New methodologies are being implemented for the spatial simulation of different alternatives, to better inform planning decisions. Such methodologies allow the integration, in the medium-long term, of different criteria (i.e. economic, social, environmental or territorial aspects), different spatial attributes (land uses, proximity to urban areas, to roads, etc.), as well as judgments from the decision makers. Increasing the complexity of the model, however, raises the uncertainty involved in its spatial output. For this reason, aiming at testing the robustness of the results, the inclusion of a validation stage in these processes is important.

From a methodological point of view, using multi-criteria analysis (MCA) techniques together with geographic information systems (GIS) has been found to be particularly efficient for the optimal allocation of land uses. Among the existing MCA techniques, weighted linear combination (WLC) is one of the most widely used, because of its simplicity (Gómez and Bosque, 2004).

The use of SA together with models based on MCA techniques is not common. However, in those cases in which SA has been used, the approach has often been to test whether selected small variations in the weights w_i of the factors X_i may cause important variations in the model results (Gómez and Bosque, 2004). SA techniques involving more complex analyses have recently been developed within the field of numerical modelling, but without a spatial

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doi:10.1016/j.sbspro.2010.05.195

dimension. Those are based on defining a probability distribution function (PDF) for each variable and for each weight. A sample is then generated from those functions and used to run the model a significant number of times, applying either local, global or screening methods (Saltelli et al., 2000). Indeed, they have been used also with spatial models, with some satisfying results (Crosetto and Tarantola, 2001; Gomez and Tarantola, 2006). However, they still have a limited application in this field, as they do not take into account the variability that generally exists in the spatial distribution of the variables included in the model. Recently, Liburne and Tarantola (2009) have proposed an adaptation of the 'Sobol' method for this kind of models, but their approach does not yet represent an explicitly spatial SA technique. It still relies on the PDF of the variables, although some modifications with respect to the uncertainty and spatial resolution of the data are included.

In this respect, the research presented here focuses on the design of an explicitly spatial SA methodology. The tools adopted have been those available in a raster GIS environment (Idrisi), and the approach undertaken resembles, as much as possible, the One-At-a-Time (OAT) factor analysis. In this way, we intend to identify the local impact of the model factors, looking at the effects produced by changes within a ±25% range in each input factor when all other factors remain unaltered.

On this basis, we propose a methodology that analyses the changes in the pixel values (the minimum spatial unit in a raster environment) of the maps representing each factor, instead of the changes in their PDF. This way, the values of the pixels are randomly modified within a certain percentage range of their initial value, and this is done for both the aptitude values of the input factors (maps) and for their weights (converted to maps).

The SA method proposed here has been tested on the results of a simulation to localise future urban growth in the region of Madrid (Spain). This simulation was developed using MCA techniques (WLC) and GIS. It started from the land cover situation in 2000 and assigned new residential land use for 2020. To do so, it considered 14 factors, each of them weighed according to its importance for land urban use. Those factors represented criteria from the environmental, economic and social categories, and included aspects such as distance to urban areas, to roads, to commercial areas, hydrography, land uses, types of soil, geotechnics, etc.

The method proposed here starts with a random change (within a ±25% range) at the pixel level for all input factors. The weight of each factor is also modified, adding at each pixel a random change of ±25% to the original value, and thus converting this numeric parameter into a map. The model is then run 14 times, modifying a different input factor and its corresponding weight together (14 models), and finally run 3 models, at level groups (3 criteria).

The SA will be conducted by comparing the outcome of each of those models with the original result, using the *Kappa* statistic. The differences in those comparisons will indicate which factors and which weights have a stronger influence on the final result. The global percentage of coincidence for the 17 maps together will also be computed, identifying which pixels have been selected most often. This will provide an idea of the robustness of the model.

Finally, the results of this procedure will be compared with those obtained when applying the Fast and E-Fast methods to the same model, using the 'SimLab' software.

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